Search for $Z_c(3900)$ in $\Upsilon(1,2S) \to \pi^+ D^0 D^{*-}$ decay at Belle

Group meeting

Wang Zhang

May 29th, 2026

Data and MC samples

$$\Upsilon(1S, 2S) \to \pi^+ Z_c(3900)[Z_c(3900) \to D^0 D^{*-}]$$

Data samples

- 5.8 fb^{-1} data sample collected at $\Upsilon(1S)$ peak $\sqrt{s} = 9.46$ GeV.
- 24.9 fb^{-1} data sample collected at $\Upsilon(2S)$ peak $\sqrt{s} = 10.02$ GeV.
- 89.5 fb^{-1} data sample collected at off-resonance $\sqrt{s} = 10.52$ GeV.(to be added)

MC simultion

- 4×10^5 signalMC(using results of PRL 112, 022001 about $Z_c(3885)$ with 0 Γ)
- 4×10^5 no-$Z_c(3900)$ MC
  - prompt D^0 decays to $K^+\pi^-$ and $K^+\pi^+\pi^+\pi^-$(each mode generated half of the sample)
  - inclusive $\bar{D}^0$ from $D^{*-} \to \bar{D}^0\pi^-$
- generic $\Upsilon(1S, 2S)$ MC samples with 3 times luminosity of data samples

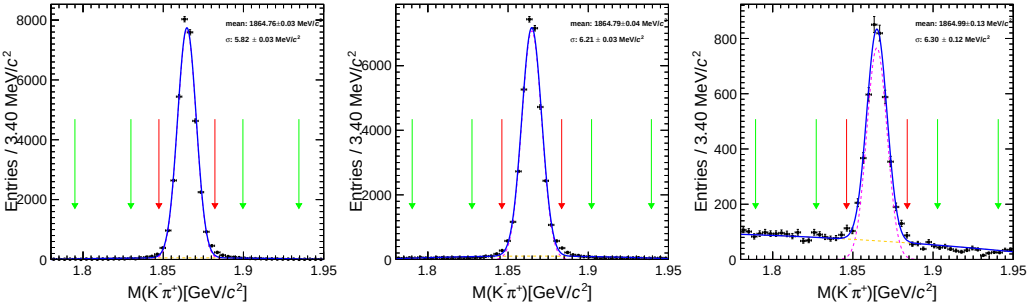
Basic Selection

- For tracks
  - $dr < 0.5$ cm and $|dz| < 2.0$ cm
  - for kaons: $\frac{\mathcal{L}(K^{\pm})}{\mathcal{L}(K^{\pm})+\mathcal{L}(\pi^{\pm})} > 0.6$ and for pions: $\frac{\mathcal{L}(K^{\pm})}{\mathcal{L}(K^{\pm})+\mathcal{L}(\pi^{\pm})} < 0.4$
- For reconstructed D^0 candidates
  - Mass Constraint with kFit
- Require $M_{\rm rec}(\pi^+ D^0) - M_{\rm rec}(\pi^+ D^0 \pi^-_{\rm slow}) < 0.20$ GeV$/c^2$ and 1.0 GeV$/c^2 < M_{\rm rec}(\pi^+ D^0) < 3.0$ GeV$/c^2$ to reduce the combinatorial background of D^{*-} candidates.

reconstructed D^0 mass fit $\Upsilon(1S)$

Signal Region: $|M(D^0_{\rm rec}) - m(D^0)| < 3\sigma_{DT}$ and Sideband Region: $|M(D^0_{\rm rec}) - m(D^0) \pm 9\sigma_{DT}| < 3\sigma_{DT}$

$D^0 \to K^-\pi^+$ mode

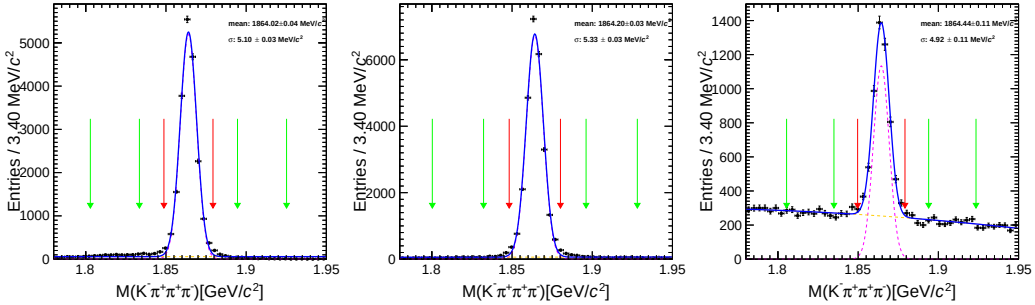


signal MC, PHSP MC and real data

	signal MC	PHSP MC	Data
mean	$1864.76 \pm 0.03\ \mathrm{MeV}/c^2$	$1864.79 \pm 0.04\ \mathrm{MeV}/c^2$	$1864.99 \pm 0.13\ \mathrm{MeV}/c^2$
σ_{DT}	$5.82 \pm 0.03\ \mathrm{MeV}/c^2$	$6.21 \pm 0.03\ \mathrm{MeV}/c^2$	$6.30 \pm 0.12\ \mathrm{MeV}/c^2$

reconstructed D^0 mass fit $\Upsilon(1S)$

$D^0 \to K^-\pi^+\pi^+\pi^-$ mode

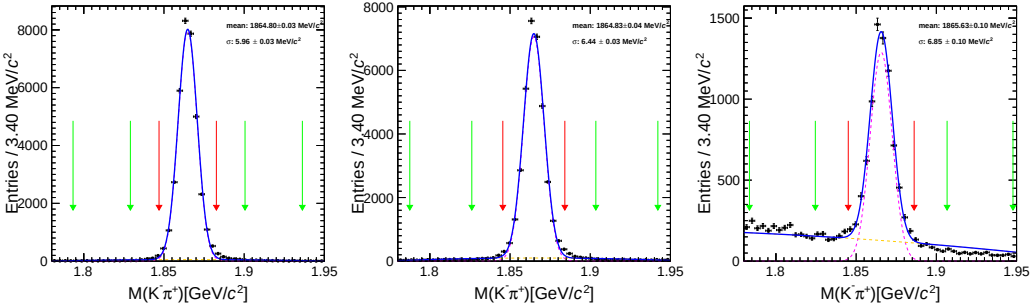


signal MC, PHSP MC and real data

	signal MC	PHSP MC	Data
mean	1864.02 ± 0.04 MeV$/c^2$	1864.20 ± 0.03 MeV$/c^2$	1864.44 ± 0.11 MeV$/c^2$
σ_{DT}	5.10 ± 0.03 MeV$/c^2$	5.33 ± 0.03 MeV$/c^2$	4.92 ± 0.11 MeV$/c^2$

reconstructed D^0 mass fit $\Upsilon(2S)$

$D^0 \to K^-\pi^+$ mode

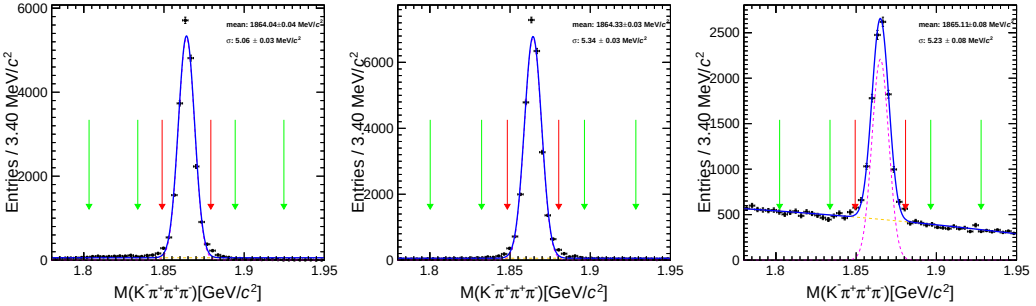


signal MC, PHSP MC and real data

	signal MC	PHSP MC	Data
mean	1864.80 ± 0.03 MeV/c^2	1864.83 ± 0.04 MeV/c^2	1865.63 ± 0.10 MeV/c^2
σ_{DT}	5.96 ± 0.03 MeV/c^2	6.44 ± 0.03 MeV/c^2	6.85 ± 0.10 MeV/c^2

reconstructed D^0 mass fit $\Upsilon(2S)$

$D^0 \to K^-\pi^+\pi^+\pi^-$ mode



signal MC, PHSP MC and real data

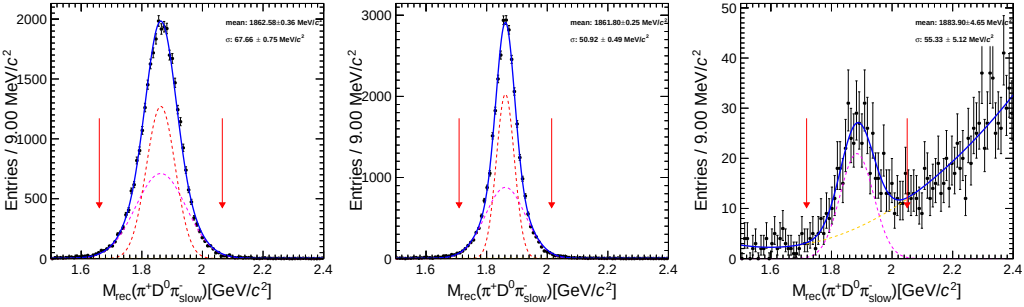
	signal MC	PHSP MC	Data
mean	1864.04 ± 0.04 MeV/c^2	1864.33 ± 0.03 MeV/c^2	1865.11 ± 0.08 MeV/c^2
σ_{DT}	5.06 ± 0.03 MeV/c^2	5.34 ± 0.03 MeV/c^2	5.23 ± 0.08 MeV/c^2

Recoil mass of $\pi^+ D^0 \pi^-_{\rm slow}$ $\Upsilon(1S)$

Mass window: $|M(\bar{D}^0) - m(\bar{D}^0)| < 3\sigma_{DT}$

$$M(\bar{D}^0) = M_{\rm rec}(\pi^+ D^0 \pi^-_{\rm slow}) = \sqrt{(E_{\rm cms} - E_{\pi^+} - E_{D^0} - E_{\pi^-_{\rm slow}})^2 - (\vec{p}_{\pi^+} + \vec{p}_{D^0} + \vec{p}_{\pi^-_{\rm slow}})^2}$$

$D^0 \to K^-\pi^+$ mode

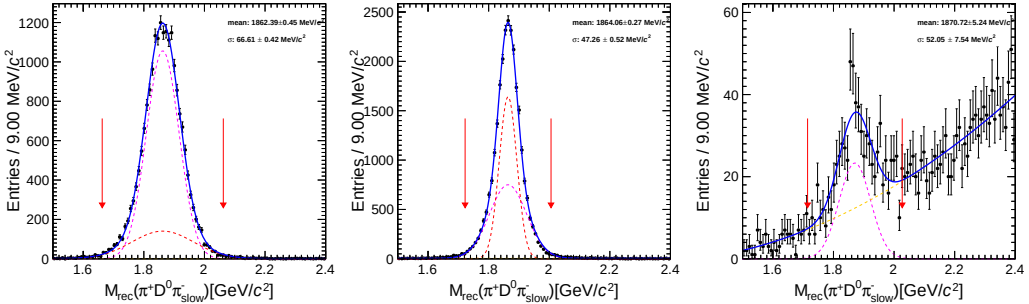


	signal MC	PHSP MC	Data
mean	1862.58 ± 0.36 MeV/c^2	1861.80 ± 0.25 MeV/c^2	1883.90 ± 4.65 MeV/c^2
σ_{DT}	67.66 ± 0.75 MeV/c^2	50.92 ± 0.49 MeV/c^2	55.33 ± 5.12 MeV/c^2

Recoil mass of $\pi^+ D^0 \pi^-_{\rm slow}$ $\Upsilon(1S)$

Mass window: $|M(\bar{D}^0) - m(\bar{D}^0)| < 3\sigma_{DT}$

$D^0 \to K^-\pi^+\pi^+\pi^-$ mode



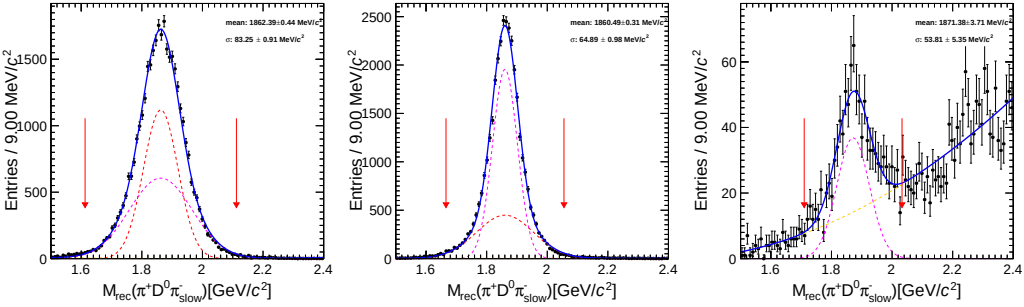
	signal MC	PHSP MC	Data
mean	1862.39 ± 0.45 MeV/c^2	1864.06 ± 0.27 MeV/c^2	1870.72 ± 5.24 MeV/c^2
σ_{DT}	66.61 ± 0.42 MeV/c^2	47.26 ± 0.52 MeV/c^2	52.05 ± 7.54 MeV/c^2

Recoil mass of $\pi^+ D^0 \pi^-_{\rm slow}$ $\Upsilon(2S)$

Mass window: $|M(\bar{D}^0) - m(\bar{D}^0)| < 3\sigma_{DT}$

$$M(\bar{D}^0) = M_{\rm rec}(\pi^+ D^0 \pi^-_{\rm slow}) = \sqrt{(E_{\rm cms} - E_{\pi^+} - E_{D^0} - E_{\pi^-_{\rm slow}})^2 - (\vec{p}_{\pi^+} + \vec{p}_{D^0} + \vec{p}_{\pi^-_{\rm slow}})^2}$$

$D^0 \to K^-\pi^+$ mode



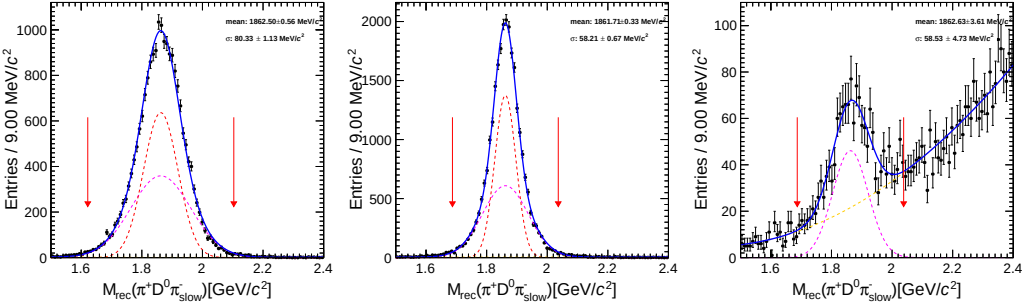
	signal MC	PHSP MC	Data
mean	1862.39 ± 0.44 MeV/c^2	1860.49 ± 0.31 MeV/c^2	1871.38 ± 3.71 MeV/c^2
σ_{DT}	83.25 ± 0.91 MeV/c^2	64.89 ± 0.98 MeV/c^2	53.81 ± 5.35 MeV/c^2

Recoil mass of $\pi^+ D^0 \pi^-_{\rm slow}$ $\Upsilon(2S)$

Mass window: $|M(\bar{D}^0) - m(\bar{D}^0)| < 3\sigma_{DT}$

$$M(\bar{D}^0) = M_{\rm rec}(\pi^+ D^0 \pi^-_{\rm slow}) = \sqrt{(E_{\rm cms} - E_{\pi^+} - E_{D^0} - E_{\pi^-_{\rm slow}})^2 - (\vec{p}_{\pi^+} + \vec{p}_{D^0} + \vec{p}_{\pi^-_{\rm slow}})^2}$$

$D^0 \to K^-\pi^+\pi^+\pi^-$ mode

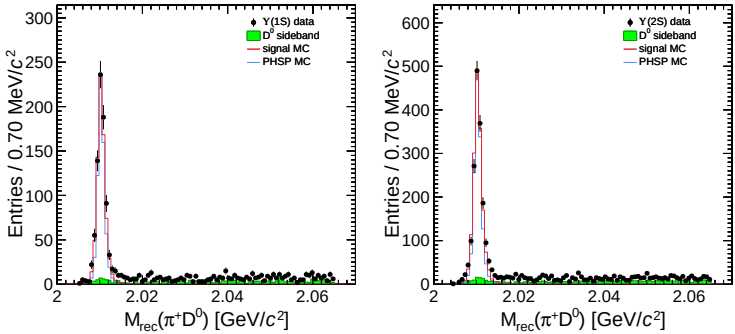


	signal MC	PHSP MC	Data
mean	1862.50 ± 0.56 MeV/c^2	1861.71 ± 0.33 MeV/c^2	1862.63 ± 3.61 MeV/c^2
σ_{DT}	80.33 ± 1.13 MeV/c^2	58.21 ± 0.67 MeV/c^2	58.53 ± 4.73 MeV/c^2

Recoil mass of $\pi^+ D^0$

$$M(D^{*-}) = M_{\rm rec}(\pi^+ D^0) = M_{\rm rec}(\pi^+ D^0) - M_{\rm rec}(\pi^+ D^0 \pi^-_{\rm slow}) + m(\bar{D}^0)$$

$\Upsilon(1S)$ $\Upsilon(2S)$



Back up

$\Upsilon(1S)$

```
========================================
Signal MC (SR) entries: 50698
Signal MC (SR) entries (D0_dmID == 1.0): 15.997
Signal MC (SR) entries (D0_dmID == 2.0): 9.352
Non-Prompt MC (SR) entries: 57326
Non-Prompt MC (SR) entries (D0_dmID == 1.0): 15.983
Non-Prompt MC (SR) entries (D0_dmID == 2.0): 12.68

>>> 1D Sideband Background Estimation <<<
Events in Signal Region (SR) : 1338
Events in Sideband (SB)      : 520 (Weight: 0.5)
Estimated Bkg in SR          : 260
Estimated Pure Signal        : 1078
========================================
```

$\Upsilon(2S)$

```
========================================
Signal MC (SR) entries: 51498
Signal MC (SR) entries (D0_dmID == 1.0): 16.4105
Signal MC (SR) entries (D0_dmID == 2.0): 9.3385
Non-Prompt MC (SR) entries: 58162
Non-Prompt MC (SR) entries (D0_dmID == 1.0): 16.3305
Non-Prompt MC (SR) entries (D0_dmID == 2.0): 12.7505

>>> 1D Sideband Background Estimation <<<
Events in Signal Region (SR) : 2736
Events in Sideband (SB)      : 1178 (Weight: 0.5)
Estimated Bkg in SR          : 589
Estimated Pure Signal        : 2147
========================================
```

Back up

veto $\Upsilon(1,2S) \to D^{*+}D^{*-}$ background

$\Upsilon(1S)$ $\Upsilon(2S)$